Textile Monopole Sensors for Breast Cancer Detection

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Abstract

This paper investigate different available breast cancer imaging methods, particularly microwave imaging techniques (MI). The building block of a radar-based microwave imaging system using a flexible antenna element that could be integrated in a clothing item. It could be accessible to women everywhere easily and at an affordable price which will help them with early breast cancer detection. Two different flexible monopole antennas on a cotton substrate are designed for radar-based microwave imaging. The ultra-wideband (UWB) fully textile sensor shaped as rectangular and circular monopole antenna for breast cancer detection (BCD) are designed. The antenna operates at impedance bandwidth $\leq -10\text{dB}$ in the operating band extend from 2.5 to 9 GHz with an overall footprint of $50 \times 50 \text{ mm}^2$. Simulated detection and bending capacity then proceeded to fabricate a breast phantom and a tumor sample with parameters that mimic these of the human breast's healthy and malignant tissue. Measurements highly match with the simulation results as well as the performance of antenna before and after subjected to washing is measured and compared. Moreover, simulations of antenna in proximity to breast model with and without tumor are also conducted. Finally the specific absorption rate (SAR) is also calculated to insure that the developed textile sensor is safe to be deployed on-body. The proposed work demonstrates the potential to develop wearable microwave imaging system using fully textile antennas.

I. Introduction

Breast cancer is expected to have around 11% percent death rate in 2020, according to WHO Cancer Country Profiles. This puts Breast cancer as the second leading cause of cancer-related death in Egypt after liver cancer [1-5]. According to an analysis of breast cancer in 187 countries, the occurrence of breast cancer has drastically increased from an average of 641,000 cases in 1980 to an average of 1,643,000 cases in 2010. Cancer is an asymptomatic disease in the early case, in which the patient experiences no evident symptoms or pain until the cancer progresses to an advanced stage [1]. These unsettling statistics demonstrate how early detection and diagnosis of cancer can be crucial for improving survival rates. Regular and safe screening can be used to keep track of this. Women over the age of 40 should get at least a scan once a year as a good role of thumb. Mostly for young women, breast cancer is diagnosed at a later stage and at higher grade with greater chance of recurrence [5]. Thus, early cancer detection is critical for successful medical treatment and cure [2]. There are plenty of methods are being used for cancer screening such as: Mammography, breast ultrasound, thermography, magnetic resonance imaging (MRI), positron emission tomography (PET), optical imaging, electrical impedance based imaging, and computed tomography (CT) [6-7]. Mammography is a widely used imaging technique for detecting breast cancer. It is a combination of ultrasound and x-ray imaging, where the malignant tissue appears brighter. It helped decreasing the mortality rate in screened women by 25–30%. Despite its undeniable success, mammograms fail in detecting cancer in its early stages and in denser breasts. It's also an expensive technique that a large portion of the population may find it difficult to access regularly [7].

CT scans are another form of X-ray imaging. Because they usually have low contrast, iodine injections are required to create a brighter, clearer picture. However, CTs are not suitable for routine scans, despite being mildly invasive, since the lifetime attributable risk (LAR) of cancer incidence was found to be highest for lung cancer and, in younger women, breast cancer [1]. Ultrasound imaging uses sound waves to form real-time images. On its own, it causes unacceptable false positive and false negative outcomes in asymptomatic women. MRIs, on the other hand, are beneficial to women who are at a higher risk of breast cancer and can be used to assess dense breasts. Its downside is that it's unable to detect early-stage cancer, takes a long time to perform, not readily available in all places, and is costly [2]. As more evidence accumulated, it became clear that non-traditional imaging methods for breast cancer imaging were required. One that is non-ionizing, cheaper and more accessible. Although Microwave imaging techniques (MWI) is relatively recent, it showed competence to fill this uprising need. The benefits of MWI include the fact that it is non-ionizing, non-expansive, and non-invasive. Due to the high contrast between normal tissue and tumors, microwave breast cancer imaging systems are promising low-cost sensing tools. Microwaves breast cancer imaging systems are promising low-cost sensing tools due to the high contrast between normal tissue and tumors. It also balances the competing requirements for resolution and penetration depth with high potential to detect small tumor at short scanning time [1, 2]. It can reduce safety hazards due to its non-ionizing nature, allowing women to receive regular breast cancer screening compared to other existing techniques [2]. The basic idea behind microwave imaging is to use one or more antennas to illuminate the target object, and then use receive antennas to capture the scattered field surrounding the target domain. The scatter data is then processed to reconstruct a map of the imaging domain.

Scattering data processing in MWI typically employs one of two broad algorithms, both of which rely on the electrical characteristics of normal and malignant breast tissues [10]. Microwave Imaging (MWI) restore the scanned image using the reflected wave from the internal breast with tumor [6, 7]. It observes changes in reflection or transmission by comparing the dielectric characteristics of normal and malignant breast tissues [6]. Several research studies support using MWI as an alternative to mammography in early diagnosis for breast cancer [6-11]. In these systems, the antenna is positioned in proximity with the human body as a single element or in arrays [2, 12]. As a result, antenna development and optimization are critical in determining the overall performance of a detection system. In addition to the newly used flexible and textile antennas, other antenna types have been described in the above-mentioned imaging systems [1, 6, 7, 11, 12-14].

Wearables have proven to be a valuable technology for imaging systems due to its low cost, low profile, thinness, and robustness, as well as its potential to be integrated into human clothing [13, 14], the demand for wearable antennas has increased as a result of the growing demand for continuous health monitoring, rapid connectivity, and IoT deceptions. The developed wearable antennas are mostly planar, specifically microstrip patch antennas, because they mainly radiate perpendicularly to the planar structure and their ground plane efficiently shields the human body [15]. The environment, transmission strength, and frequency range all influence antenna selection and design in any application. The antenna's performance is also influenced by the material used, the fabrication technique used, and the

substrate properties [16]. However, limited research groups are working on developing wearable microwave imaging systems for breast cancer detection or imaging with textile sensors [6, 7, 9, 13, 14, 15]. The wearable system from Montreal University reported in [6, 7, 9] uses flexible microstrip antennas to easily develop to a wearable system, and flexible substrate for the PCB that provides all signal routing, system assembly and calibration. The flexible antenna substrate material have low dielectric loss, relatively low permittivity, low coefficient of thermal expansion, and high thermal conductivity [18]. Three types of substrates have often surfaced in the fabrication of flexible antennas: thin glass, metal foils, and plastics or polymer substrates [16].

The wearable flexible system consists of 16 monopole antennas arranged in an array that operates between 2 and 5 GHz and is embedded in a bra [7, 9]. The antennas will be in contact with the skin by placing it on the inner surface of the bra. This placement excludes any uncertainty regarding the breast position relative to the measuring system and sensors. In [9], monopole antennas are fabricated on Kapton flexible substrate to maintain adequate coverage of the breast and allows elements to take the shape of the breast. In [13], a compact UWB purely textile monopole antenna is developed that is applicable to be embedded in wearable microwave imaging systems. Polyester fabrics serve as the substrate, with conductive copper polyester taffeta fabric serving as the radiating elements and ground. The antenna structure in [13] shows two triangles and a few parallel slots to increase the current path. This results in an UWB range from 1.198 to 4.055 GHz (109%). Many conductors are suited and have previously been used in the manufacture of flexible antennas. Silver conductor yarn, Metal-nano particles (silver and copper), conductive polymers, graphene based materials and liquid metals [2]. However, for textile antennas, a conductive thread or fabric is usually used [18]. In [13], measurements in contact with tissue-mimicking phantoms with little effect on the operation of the antenna are conducted. In [14], an embroidery triangular textile antenna with shorting pins is proposed at 5.8 GHz with bandwidth 210 MHz. Under bending conditions, the antenna in [14] maintains safe SAR values and stability. Though the antenna in [14] acquires 4.1 dBi gain, it acquires only 3.8% bandwidth which does not fit imaging applications. Moreover, the effect of washing cycles on the antenna performance was not addressed. Textile substrates are increasingly being used for wearable antennas and sensors since they provide comfort and flexibility at a low cost [13]. Thus, the designed textile antennas combine traditional textile materials with new technologies and acts as interface of the human-technology-environment [13].

In this paper, a comparative study of different shapes of fully textile UWB monopole antennas are presented as shown in Fig. 1. The proposed antennas are designed with the potential of integration into women's clothes for monitoring breast and detecting any abnormalities in its tissues. Reflection $|S_{11}|$ and Transmission $|S_{21}|$ coefficients are collected and compared for the proposed sensor with and without tumor inserted in a breast phantom model. This paper is extension to the work published in [18] which included rectangular shaped monopole only. The study in [x] only include simulations of rectangular monopole in proximity to breast phantom with and without tumor as well as measurements in air (wet & dry). However, in this paper, breast and tumor phantom model is synthesized, fabricated and characterized. Measurements in proximity to breast phantoms with and without tumor are also added

and presented. Moreover, a comparative study of shape of radiator either rectangular or circular in terms of sensing over body is included as well as comparison with similar structures in literature.

The organization of the paper after an introduction, in Section II, design and simulation of textile proposed antennas various types of monopole antenna shaped for the wearable antennas are discussed. Section III describes the measurements of the proposed textile antennas. Section IV described the simulations of textile monopole antenna in the present of breast phantom model. In section V described the measurements of proposed textile antenna in proximity to breast phantom model then the whole paper is conclude in the conclusion section VI.

II. Design And Simulations Of Textile-based Monopole Antennas

In this paper, textile technology is chosen to build all proposed structures. This implies that radiator, ground and substrate are composed of textile materials. Regarding the substrate, Cotton is favoured among other textile alternatives [18]. This owes to its good properties in terms of comfortable, absorbing human sweat, no allergy, easy fabrication, low price as referred to in [18, 9, 15]-[19-24]. Data of several textile materials that can be used as substrate is reported in [18] as well as fabrication challenges. Among theses, some fabrics are not suitable or stable enough for a wearable antenna, effects of washing cycles on fabric and developing a precise pattern and controlling accuracy of dimensions [19, 24]. Cotton substrate has rated electrical properties: dielectric constant (ϵ_r) of 1.4-1.8 and loss tangent ($\tan \delta$) of 0.05-0.08 with height of 2 mm [20-22]. Two proposed textile monopole antennas are studied and compared in FCC band from 1 GHz to 6 GHz with dimensions width (W_s) of 50 mm and length (L_s) of 50 mm for the substrate.

The first monopole acquires a radiator with rectangular shaped with width (W) of 17 mm, length (L) of 22 mm. While the ground plane has width (W_g) of 50 mm, and length (L_g) of 17 mm. On the other hand, the second monopole antenna with circular shape has radius (R) of 14 mm, length (L) of 16 mm. Ground plane for circular-shaped monopole has width (W_g) of 50 mm, and length (L_g) of 14.7 mm. A 50 Ω transmission feeding line (W_g) of 3 mm is shown in Fig. 1 (a) for rectangular patch while 3.2 mm for circular one as shown in Fig. 1 (b). Two types of conductors were assigned in simulations for radiators and ground plane. The first one is copper clad conductor with thickness 0.5 mm while the second one is silver conducting fabric with sheet resistance of 0.5 Ω / square. The given dimensions and simulations are chosen after optimization through two different electromagnetic field simulators; CST studio suite Ver. 2020 and high frequency structure simulation (HFSS) ver. 17. From the reflection coefficient results of comparable performance is recorded with both types of conductors for rectangular and circular monopole antennas at Fig. 2 (a) and Fig. 2 (b), respectively.

Moreover, the gain of the proposed shaped antennas using both conductors are simulated and compared in Fig. 3(a) and Fig. 3(b). Fig. 3 shows that the simulated gain for both proposed monopole antennas of the antenna using copper clad conductor antenna is higher gain than textile fabric for frequencies less than 3 GHz. While in the frequency range from 3 GHz and 5 GHz both antennas acquire similar gain

values. Thus, textile conductors could be used in building radiators and ground for the proposed antennas.

lii. Measurement Results

The two proposed antennas are fabricated as shown in Fig. 4 (a) and Fig. 5(a). Both figures show the front and back view of the antennas. Both antennas are tested and measured using a vector network analyzer (Anritsu MS4647A). The magnitude of reflection coefficient ($|S_{11}|$ in dB) for both measured and simulated data for both antennas are shown in Fig. 4(b) and Fig. 5 (b). The rectangular monopole antenna has measured reflection coefficient of -29 dB, -40 dB at 2.5 GHz and 6.3 GHz while -20 dB, -18 dB at 3.1 GHz and 5.5 GHz for circular monopole antenna. As the proposed antennas are anticipated to be embedded in clothes as on-body sensors, the effect of wetting conditions is also included in the study. This is realized by recording the response of the fabricated antennas at dry, immersing the antenna in tape-water container (wet condition) and after getting dry. The wet response for both proposed prototypes (rectangular and circular) are shown in Fig. 6(a) and Fig. 6(b).

From measurements, both antennas preserve its response after immersing in water and dry out. Thus, they could be embedded in clothes to act as on-body sensors to monitor vital signs or for cancer screening. Though the proposed structures acts as wearable sensors, the far field radiation properties are recorded in Fig. 6 and Fig. 7 at $\phi = 0^\circ, 90^\circ$ and $\theta = 90^\circ$. The radiation patterns for proposed monopole antennas with rectangular and circular are recorded in both free space and when mounted on body are shown in Fig. 7(a) to (c) and Fig. 8 (a) to (c) at resonant frequencies 2.5 GHz and 3.1 GHz. Though, there are many repels created when the antennas are placed on body, omnidirectional operation are still maintained.

Given that textile antennas is flexible and conformal, the effect of bending antennas in both X- and Y- directions are simulated and recorded. Different bending angles of $0^\circ, 45^\circ, 75^\circ$ and 90° are used in simulations and presented in Fig. 9 and Fig. 10. From given figures, it could be concluded that rectangular shaped antennas maintain its operation after subjected to bending in either X- or Y-directions compared to circular one.

Iv. Simulations Of Textile Monopole Antenna In Proximity To Breast Phantom Model

The basic composition of a human breast consists of glandular tissue, adipose tissues (fat), fibrous tissues covered with a skin layer [22]. Breast are classified into four classes according to their density where: mostly fatty, scattering fibro glandular, heterogeneously dense and, extremely dense [23-24]. Breast density will affect the dielectric properties as it simply represents the amount of fat or fibro glandular tissues. A surveyed the literature hunting for the most suitable phantoms for imitating the desired behavior. The ideal microwave breast phantom should mimic the electromagnetic properties of the heterogeneous breast tissues, its geometry, provide an easy way to insert the tumor phantom and it

should be durable for long periods. Three major classes are found for such phantoms as chemical phantoms (oil in gelatin mixtures can mimic the four types of breast by varying the percentage of oil in the mixtures), numeric phantoms (provided by different simulation programs prove to be the most accurate in mimicking breast tissues, as CST) and 3D printed phantoms.

The performance of the two proposed antennas (rectangular & circular monopoles) in contact to breast tissues with and without tumor will be studied. The dimensions and electrical properties of the four layer phantom model embedded in simulation are presented in [25, 18] and shown in Fig. 11. The tumor size used in the simulation is 10 mm diameter with electrical properties as reported in [9] and shown in Fig. 11. The tumor is placed at distance 60 mm in approximately in the center of the phantom. In the given study, two simulation scenarios were adopted. The first scenario starts by placing one sensor/ antenna in contact to breast phantom as shown in Fig. 11(a) while the second scenario using two sensors/ antennas at two opposite sides of the breast model as shown in Fig. 11(b). These two scenarios will allow recording the reflection coefficient (S_{11}) and transmission coefficient (S_{21}). In all simulations, the antenna is positioned above the breast with a distance of 2 mm filled with cotton substrate as illustrated in Fig. 11(b). Results shown in figures 12-15 are the simulations using breast tissue models with and without tumors [8, 26].

Figure 12 and Fig. 13 show magnitude and phase of reflection coefficient for both rectangular and circular monopoles with and without tumor, respectively. Figure 12 shows that the tumor increased the magnitude of the reflection coefficient by 1 dB and induced a shift of 100 MHz at lower resonant band at 1.1 GHz for rectangular monopole. At higher resonant frequency at 5 GHz, it changes the magnitude of reflection coefficient by 10 dB and reduced the resonant by 500 MHz. For circular monopole, the tumor increased the magnitude of the reflection coefficient by 3 dB and induced a shift of 50 MHz at lower resonant band at 3.7 GHz. At higher resonant frequency at 5.5 GHz, it changes the magnitude of reflection coefficient by 2 dB and reduced the resonant by 50 MHz as shown in Fig. (13). In Fig. 14, using two rectangular antennas, the tumor induced a shift of 500 MHz in resonant frequency, reduced the reflection by 8 dB and induced around 300° phase shift. On the other side, for circular monopole, the tumor induced a shift of 300 MHz in resonant frequency, reduced the reflection by 10 dB and induced around 100° phase shift. Thus, using two monopole antennas on the breast provides more data required to detect tumors as shown in Fig. 15.

Given that the proposed sensors are designed to be embedded in women's clothes or in contact to human body, the SAR values are calculated using CST simulator, Ver. 2020. SAR as the specific absorption rate is defined as the amount of power absorbed per unit mass of tissue as reported in [14]. The simulated SAR is calculated by placing the antenna model on the phantom tissue model as shown in Fig. 10. The numerically safe SAR values at resonance frequency value at 1 g and 10 g of tissue based on the IEEE C95.3 standard for a device are 1.6 W/Kg and 2 W/Kg respectively. For the rectangular monopole, it realizes SAR values of 2.32 W/Kg and 0.98 W/Kg as shown in Fig. 16. However, circular monopole antenna is 3.66 W/Kg and 0.98 W/Kg, respectively at 100 mW transmitted power. Safety SAR levels could

be maintained for the proposed textile antennas as long as transmitted power do not exceed 100mW. Thus the proposed antenna could be embedded in wearable applications.

The mixture reaches the required temperature, the calibrated amount of agarose is added. On the other hand, the tumor requires 100 ml deionized tri-distilled water, 60 ml ethanol, 1 g NaCl and 1.5 g agarose. All mixtures (breast & tumor phantoms) are held on a magnetic heating stirrer HJ-3A available in the faculty chemistry lab. Using a thermometer, a continuous monitoring process was being held every few minutes to check the temperature of the solution. All prepared mixtures for breast and tumor phantoms are let to cool down and set to a gelatinous constancy. All containers carrying phantoms are sanitized to avoid any impurities and keep the electrical properties of the fabricated phantoms. The electrical properties of all phantoms (breast & tumor) are characterized using Dielectric probe **DAK-3.5-TL2**: 200MHz-20GHz. The measured dielectric constant (ϵ_r), loss tangent (ϵ'') and conductivity for both breast and tumor phantoms are shown in Fig. 16 (a)-(d). The given measured data is highly comparative to data published in literature for electrical properties of breast and tumor [25].

The proposed antennas are tested in the presence of fabricated breast phantom with and without tumor. The measured reflection coefficient results are shown in Fig. 17 for both rectangular and circular monopoles. Fig. 17 and Table 1 shows the comparison performance of two proposed monopoles shaped (rectangular/ circular). From the given results in this work and Table 1, Circular monopole acquires higher gain compared to rectangular monopole. On the other side, rectangular monopoles acquires better detection results compared to circular monopole in same band, require less power and lower SAR levels. Moreover, the proposed textile monopoles are compared to textile antennas reported in literature [26-28] and presented in Table.2. The proposed textile monopole antennas.

Table 1
The performance comparison of two proposed monopoles shaped
(rectangular/ circular).

Shape Comparison	Rectangular Monopole	Circular monopole
Bandwidth	2 to 6 GHz	2.8 to 9 GHz
Gain	2.5 dBi	5 dBi
Power required	Low	High
SAR	1.16	3.6
Fabrication	Easy to fabricate	Hard to fabricate
Practical results	Better detection	Decent detection

Table 2
The comparison of rectangular monopoles shaped and other previous published paper.

Ref.	Bandwidth (GHz)	Gain (dBi)	Dimensions (W×L×h) mm ³	Fabrications	SAR (W/Kg) in 10g
[26]	2.38-2.58	NM	70×70×3	Difficult (four layers)	0.23
[27]	7-28	Peak 10	60 × 50 × 0.7	Moderate (two layers)	1 in average
[28]	8-12	Peak 5.6	37.5×44.33×1	Easy (one layer)	0.72
Proposed	1.8 to 9	Average 4	50×50×2	Easy (one layer)	1.16
NM(not mention in the paper).					

V. Conclusion

Breast cancer is a wide-spread issue that affects many people's lives. Proper monitoring can significantly improve survival rates. Microwave imaging is a promising new screening method that could be optimized for the purpose of regular breast cancer screening as it is non-ionizing, non-invasive and cheap. It mainly depends on the difference between the dielectric and conductive properties of normal and malignant tissue. This paper present two different monopole shaped of low cost as rectangular and circular shaped, conformal fully textile antenna-based sensor operating within the band of 2 to 6 GHz. The proposed monopole antennas with size $50 \times 50 \text{ mm}^2$ is fabricated using cotton substrate and textile conductor. The proposed textile sensor retains its operation after subjected to washing and dryness. The rectangular and circular monopole shaped are fabricated and tested. The recorded results of two types of monopole using one and two sensors in contact with breast model verify the ability of the proposed sensor to differentiate normal and malignant breast tissues. The SAR of the proposed two monopole antennas are also tested and they are produced SAR value less than standard requirement. Both antennas design provide promising tumor detection capabilities. However, the rectangular monopole gives more good results in the breast cancer detection than circular monopole. The fully textile sensors are a step towards developing wearable microwave breast imaging system. This will help women to receive regular breast cancer screening safely specifically young women.

Vi. Declaration Of Interest Statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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Figures

Figure 1

Configuration of the proposed monopole antennas (a) Rectangular and (b) Circular shaped.

Figure 2

Simulated reflection coefficient in dB for the two antennas using copper clad and Silver for monopole antenna (a) rectangular and (b) circular.

Figure 3

Simulated gain versus frequency for the two antennas using copper clad and Sliver for monopole antenna (a) rectangular and (b) circular.

Figure 4

(a) Fabricated rectangular monopole antenna showing front & back views and (b) Reflection coefficient ($|S_{11}|$ in dB) of the prototype (Simulated and Measured).

Figure 5

(a) Fabricated circular monopole antenna showing front & back views and (b) Reflection coefficient ($|S_{11}|$ in dB) of the prototype (Simulated and Measured).

Figure 6

Antenna reflection coefficient at wet and dry condition (a) rectangular monopole and (b) circular monopole.

Figure 7

The 2D polar radiation pattern of rectangular monopole antenna (a) $\Phi=00$, (b) $\Phi =900$, and (c) $\theta =900$ at 2.5GHz, proposed antenna in free space (solid red) and on body (dash black).

Figure 8

The 2D polar radiation pattern of circular monopole antenna (a) $\Phi=00$, (b) $\Phi =900$, and (c) $\theta =900$ at 2.5GHz, proposed antenna in free space (solid red) and on body (dash black).

Figure 9

The effect of bending on X axes monopole antennas performance (a) Rectangular shaped and (b) Circular shaped.

Figure 10

The effect of bending on Y axes monopole antennas performance (a) Rectangular shaped and (b) Circular shaped.

Figure 11

Three layers model of breast in [15] with and without tumor tested using (a) one antenna and (b) two antennas.

Figure 12

Simulated $|S_{11}|$ of rectangular monopole antenna with and without tumour $|S_{11}|$ (a) magnitude in dB and (b) phase in degrees.

Figure 13

Simulated $|S_{11}|$ of circular monopole antenna with and without tumour $|S_{11}|$ (a) magnitude in dB and (b) phase in degrees.

Figure 14

Simulated of two rectangular monopole antennas with breast model (a) magnitude $|S_{11}|$ in dB, (b) $|S_{11}|$ phase in degrees (c) magnitude $|S_{21}|$ in dB and (d) $|S_{21}|$ in degrees.

Figure 15

Simulated of two circular monopole antennas with breast model (a) magnitude $|S_{11}|$ in dB, (b) $|S_{11}|$ phase in degrees (c) magnitude $|S_{21}|$ in dB and (d) $|S_{21}|$ in degrees.

Figure 16

Breast phantom and tumor measured dielectric properties by using DAK.

Figure 17

Measured the monopole antenna with inserted photo of breast phantom with and without tumor (a) Rectangular monopole antenna and (b) Circular.